FISHERY STOCK ASSESSMENT MODELS

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When Lengths Are Better Than Ages: The Complex Case of Bocaccio

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Abstract

Bocaccio *(Sebastes paucispinis)* has historically been the most important rockfish harvested in the California groundfish fishery. A stock assessment of bocaccio in the Eureka-Monterey-Conception area indicated that in 1996 spawning biomass was 5-10% of that present in 1970. This finding was based on the application of the Stock Synthesis model to a split-sex population, assuming length-dependent gear selectivities for four distinct fisheries. A variety of fishery-dependent and fishery-independent data sources were used to model population biomass, including (1) landings from the trawl, setnet, hook-and-line, and recreational fisheries, (2) trawl catch-at-age data for the period 1980-1985 using surface otolith ages, (3) trawl catch-at-age data for 1988, 1991, and 1994 using break-and-burn otolith ages, (4) a probability transition matrix for conversion of age types, (5) length composition data from each fishery over the period 1980-1994, (6) an effort index in the recreational fishery, (7) triennial shelf trawl survey CPUE and length-frequency data, (8) a spawning biomass index derived from larval abundance in CalCOFI surveys, and (9) an index of year-class strength from a midwater trawl survey of young-of-the-year pelagic juvenile abundance.

An evaluation of these diverse sets of information indicated that the age composition data were in fundamental disagreement with all other data sources. This discrepancy was apparently due to bias and imprecision in bocaccio ages, which resulted in uninformative age composition data

that were incapable of resolving a highly variable pattern of recruitment to the fishery. For this purpose, length composition data were much more useful, especially including those from the trawl and recreational fisheries.

Introduction

The need to incorporate diverse sets of information into the statistical analysis of fish population dynamics has led to the development and evolution of flexible stock-assessment models (e.g., Fournier and Archibald 1982; Deriso et al. 1985; Methot 1989, 1990). Along the West Coast of the United States, Methot's Stock Synthesis model has become the standard analytical tool for estimating the population status of groundfish stocks. Within the framework offered by the synthesis model, the inclusion of catch-at-age data has been the cornerstone of most groundfish assessments. Like Fournier and Archibald's (1982) model, Stock Synthesis plausibly treats age composition data as measured with a multinomial error structure, but it is unique in that errors attributable to reader mis-aging can also be included in the model.

In a broader context, the use of catch-at-age data in fish stock assessments has been reviewed by Megrey (1989). It is widely presumed that estimates of the age composition of the catch are the most informative and useful data one can obtain when modeling the effects of fishing on a stock. This is particularly true of species that show a variable pattern of recruitment, as is typical of the rockfishes (*Sebastes*). Even so, a number of studies have highlighted the benefits of including "auxiliary" data in age-structured stock assessments, especially in terms of constraining the fits of population models to catch-at-age data (e.g., Bence et al. 1993; Hightower 1996).

Here we report on certain findings from a recently completed stock assessment of bocaccio *(Sebastes paucispinis)* which employed the Stock Synthesis model (detailed results available in Ralston et al. 1996). The assessment was notable in that a large number of fishery-dependent and fishery-independent data sources were involved in the analysis. Two of the fishery-independent data sources were new and had not been used previously in groundfish stock assessments conducted on the West Coast. We also included new break-and-burn age-frequency distributions in the assessment, as recommended by Bence and Rogers (1992), and evaluated the relationship between those data and the surface age composition information that had been used in the last stock assessment.

Bocaccio is an important species of rockfish that has a long history of exploitation in California (Fig. 1; Lenarz 1987, Ralston et al. 1996). It is most abundant off southern and central California and is uncommon between Cape Mendocino and Cape Blanco. A second population center exists near the Oregon-Washington border, and extends north to Cape Flattery (Gunderson and Sample 1980, Ralston et al. 1996). Bocaccio frequents an

exceptional diversity of habitats, including kelp forests, rocky reefs, mid-water, and open, low relief bottoms (Eschmeyer 1983). Even though sub-adult growth can be very rapid in absolute terms (24 cm at age 1), adults grow slowly ($K = 0.11$-0.13 yr^{-1} [Wilkins 1980]). Moreover, growth is sexually dimorphic, with females reaching much larger sizes than males (i.e., 90 versus 70 cm).

Sources of Data

Fishery-Dependent Data

The assessment was restricted to California because Oregon landings of bocaccio are virtually nil and few biological samples were collected for the small catches taken from the Washington subpopulation. California commercial landings statistics for the period 1980-1995 were summarized using procedures outlined in Erwin et al. (1997) and Pearson and Erwin (1997). Estimates of recreational landings, which have been significant, were extracted from the national Marine Recreational Fishery Survey Statistics (MRFSS) database. The catch time series was lengthened to encompass the 1950-1995 period using information and methods detailed in Ralston et al. (1996). During the last half century, bocaccio have been harvested in four distinct sectors, i.e., the trawl, hook-and-line, setnet, and recreational fisheries (Fig. 1). Each fishery has been characterized by a distinct exploitation pattern, and in the assessment each was modeled independently of the others.

Bocaccio age composition data from the trawl fishery were available for use in the assessment, although all data for the 1980-1985 period were based on surface ages (Table 1), which were thought to be biased low for older fish (Beamish 1979). To estimate the age bias of these fish, 612 bocaccio that had been surface-aged in 1983-1984 were re-aged using the break-and-burn method. That study showed that at a break-and-burn age of 10-yr the mean surface age of bocaccio was 8-yr, while at a break-and-burn age of 20-yr, surface age averaged 14-yr. These results were further analyzed and a probability transition matrix was developed to transform model age composition vectors to predicted surface age composition vectors. The matrix was included in the Stock Synthesis model as a means of generating predicted surface age data from the underlying dynamics of the model. The 1980-1985 surface age data were also supplemented with break-and-burn age data from the trawl fishery for the years 1988, 1991, and 1994 (Table 1). Last, the precision of break-and-burn ages was evaluated by re-examining 25% of all the aged fish. Based on these 275 otoliths, percent agreement between readings declined from ~90% for age-1 fish to ~10% agreement for age-20 fish. The pattern of decline reflected an exponential decay in the precision of age estimates with increasing age (Fig. 2).

Sex-specific length compositions were also available for each year and each of the three commercial fisheries for the period 1980-1994 (Pearson
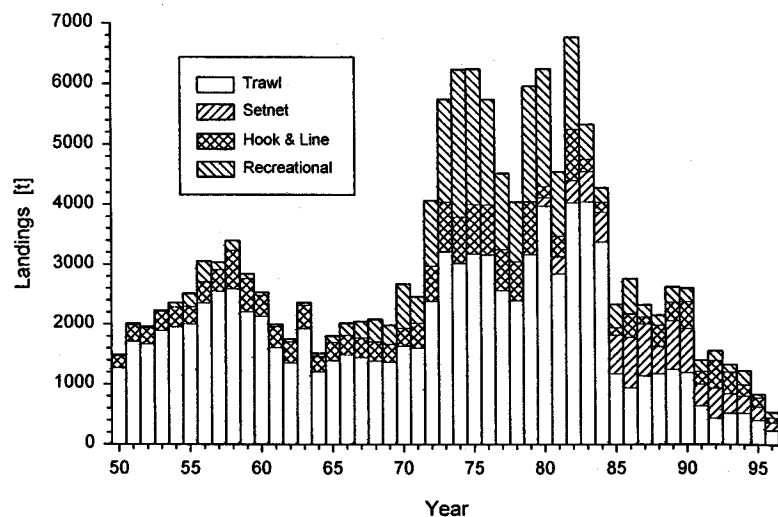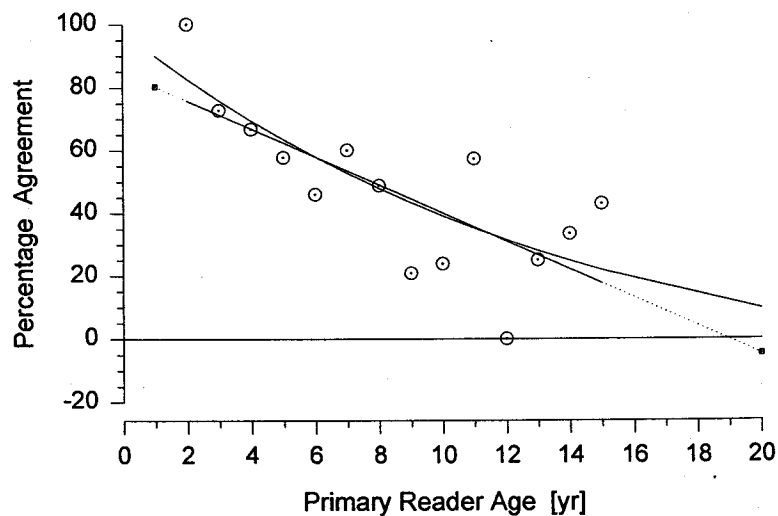
Figure 1. Estimated landings of bocaccio in the Eureka-Monterey-Conception INPFC areas during the last half century.

Figure 2. Precision of bocaccio break-and-burn age data, as measured by percent agreement to the year among re-examined otoliths. Lines represent linear and exponential fits.

Table 1. Sources of data and information used in the Stock Synthesis model of the Eureka-Monterey-Conception bocaccio stock during the 1969-1996 period.

Fishery Dependent
Trawl landings[a]
Trawl length composition[a]
Trawl surface age composition[c]
Trawl break-and-burn age composition[c]
Hook-and-line landings[a]
Hook-and-line length composition[b]
Setnet landings[a]
Setnet length composition[b]
Recreational landings[a]
Recreational length composition[a]
Recreational fishing effort[a]

Fishery Independent
Triennial trawl survey CPUE[a]
Triennial trawl survey length composition[b]
Pelagic juvenile rockfish survey[a]
CalCOFI larval abundance index[a]

[a] Primary data types (see Model Results section).
[b] Secondary data types.
[c] Tertiary data types (i.e., age composition data)
Note that recreational landings from 1990-92 were interpolated (+).

and Erwin 1997). In contrast, length composition data for the combined-sex recreational fishery were available from the MRFSS database for 1981-1989 and 1993-1995, as was a recreational fishing effort series (Table 1).

Fishery-Independent Data

Three sources of auxiliary survey information were used in the bocaccio assessment. These included the Alaska Fisheries Science Center's triennial shelf survey, the Southwest Fisheries Science Center's (SWFSC) pelagic juvenile rockfish midwater trawl survey, and the California Cooperative Oceanic Fisheries Investigation's (CalCOFI) ichthyoplankton surveys. A brief description of each follows.

The triennial bottom trawl survey has been completed once every three years since 1977 (Table 1). The survey, which has found very widespread use in Pacific coast groundfish stock assessments, samples continental shelf habitats in the 55-366 m depth range using a high-opening Nor'eastern bottom trawl equipped with bobbin roller gear (Wilkins 1996). In this study, only standard trawls conducted in the southern area (Eureka, Monterey, and Conception International North Pacific Fisheries Commission areas) were used. Although the survey is often used to provide swept-area estimates of absolute biomass, we treated the survey as a relative index of bocaccio abundance (Fig. 3). The triennial survey indicates that a substantial reduction in bocaccio biomass has occurred over the last two decades. Catch-weighted estimates of year-specific and sex-specific length compositions from the survey were also used as input data to the model.

The pelagic juvenile rockfish midwater trawl survey is designed to estimate the relative year-class strength of a group of 10 rockfish species, including bocaccio. The survey has been conducted every year since 1983 and uses a modified Cobb midwater trawl. A series of 36 standard stations are sampled during three repetitive occupations of a 110-mile study area along the central California coast. Stratified means are calculated that represent the average number of 100-day-old fish taken during a standard trawl, with the maximum value among the three occupation means providing an estimate of year-class strength (see Ralston and Howard 1995). In this instance the time series was shifted forward by one year, representing the relative abundance of age-1 bocaccio recruits (Table 1, Fig. 4). Note that the relatively low abundance of age-1 fish in 1984 and 1993 was due to the adverse effects of the 1983 and 1992 El Niños on rockfish reproductive success.

Within the California Current ecosystem, CalCOFI data have been collected over a grid of north-south lines and onshore-offshore stations since 1951. Within that time period cruises are typically identified by the year and the principal month of sampling. At occupied stations, plankton samples have been collected using both bongo and ring nets; samples are later sorted in the laboratory. The ichthyoplankton are identified and
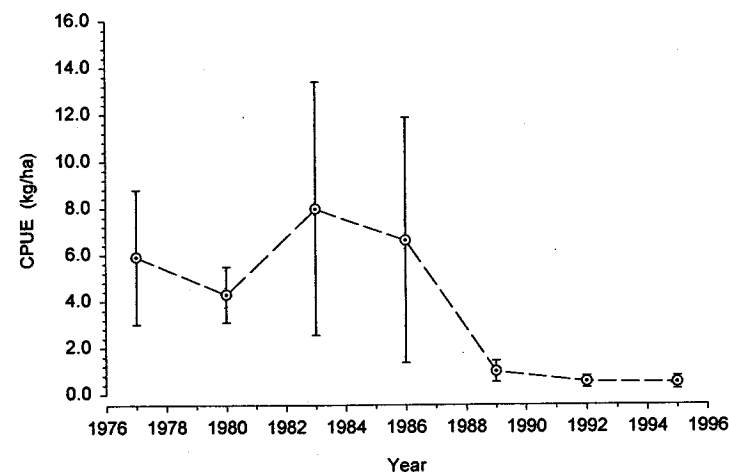

Figure 3. *Alaska Fisheries Science Center's triennial shelf trawl survey catch-per-unit-effort (CPUE) of bocaccio in the Eureka-Monterey-Conception INPFC areas. Error bars represent ± 1.0 standard error.*
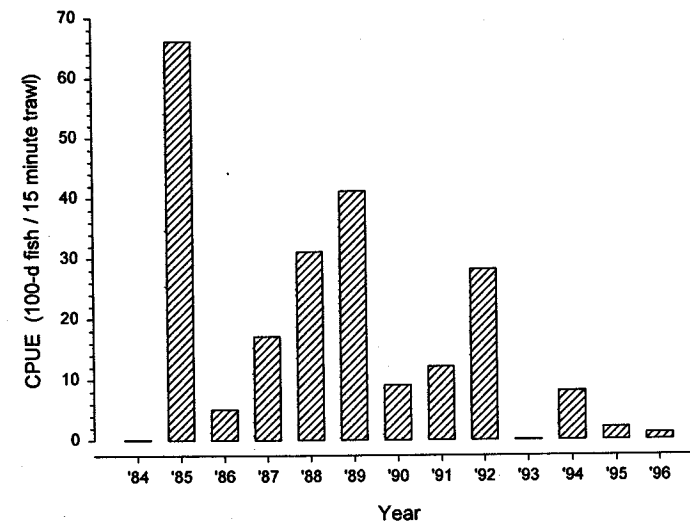

Figure 4. *Relative year-class strength of age-1 bocaccio in year t based on the abundance in year t-1 (data from the pelagic juvenile rockfish midwater trawl survey). Note that low survey catches in 1983 and 1992 were associated with El Niño events.*

enumerated when possible and the information entered into the CalCOFI database (Moser et al. 1993). Bocaccio larvae are relatively easy to identify, but have not been sorted from the entire time series of CalCOFI collections (see Table 1 for available years). Jacobson et al. (1996) describe the use of the log-transformed data to index the abundance of bocaccio larvae using a General Linear Model (GLM), which included terms for year, month, line, station, and all non-year interaction terms. Because the survey primarily samples very young larvae, year effects from the GLM can be used to provide an index of spawner abundance (Fig. 5).

Model Structure

The Stock Synthesis model is a forward-projecting, separable, age-structured population model. The separability assumption requires that the fishing mortality rate experienced by fish of age a in year t $(F_{a,t})$ is defined by the product of a year-specific full-selection instantaneous fishing mortality rate (F_t) and an age-specific value of selectivity (s_a), i.e., $F_{a,t} = F_t s_a$. Key features of the model are that it incorporates a multinomial error structure for both age and length composition data, it explicitly models aging errors when constructing predicted age composition data, and it conveniently allows a variety of data elements to be combined and evaluated under one umbrella formulation. In particular, all data types are combined in a total $\log_e$-likelihood equation of the form:

$$\ell_{Total} = \sum_{i=1}^{m} \ell_i \lambda_i$$

where ℓ_{Total} is the total $\log_e$-likelihood of the model and the ℓ_i are the individual $\log_e$-likelihoods for each of the m data components used by the model. These are weighted by "emphasis" factors (λ_i), such that in combination the various data sources used by the model can be controlled. To reduce the influence of one data type the particular λ_i can be reduced to a nil emphasis (e.g., 0.001).

The model is typically configured to treat observations of age composition data to be measured with a multinomial sampling error structure. In particular, a $\log_e$-likelihood component for the ith type of age data takes the form:

$$\ell_i(p \mid \hat{p}) = \sum_t n_{i,t} \sum_a p_{i,a,t} \log_e(\hat{p}_{i,a,t})$$

where $p_{i,a,t}$ is the observed proportion of fish that are age a in samples collected in year t, $\hat{p}_{i,a,t}$ is the model's prediction of that proportion, and $n_{i,t}$ is the year-specific sample size upon which the observed proportions are based. The model then performs an iterative search for values of $\hat{p}_{i,a,t}$
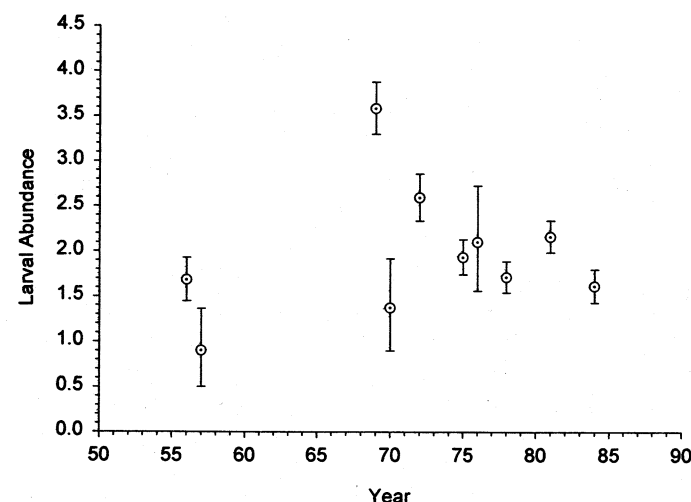
Figure 5.   *Long-term patterns in the abundance of larval bocaccio, as estimated by a General Linear Model (GLM) applied to the CalCOFI data base. Error bars indicate 95% confidence intervals.*

that will maximize ℓ_i. Length composition data are fitted in a similar manner. Survey data, however, are usually modeled with a lognormal error term, i.e.,

$$\ell_i = -\sum_t \left[\log_e(\sigma_{i,t}) + \frac{\log_e(I_{i,t} / \hat{I}_{i,t})^2}{2\sigma_{i,t}^2} \right]$$

where ℓ_i is the $\log_e$-likelihood component for the ith survey, $I_{i,t}$ is the observed value of the survey index in year t, $\hat{I}_{i,t}$ is the model's prediction of the index value, and $\sigma_{i,t}$ is the standard error of the statistic on $\log_e$-scale.

During the development of a baseline model for bocaccio, we explored a number of different configurations. Since the level of data and model complexity was very high (four fisheries, split sexes, unbiased and biased ages, three surveys, etc.), we decided some simplification was needed. First, because there were only estimates of total catch for the period 1950-1968, we elected to exclude that period and we modeled the population from 1969 to the present. Even so, data from the omitted period were used to establish historic catch levels. Although some CalCOFI data were

Table 2.   Summary of parameters estimated in the baseline Stock Synthesis model of bocaccio (M was fixed at 0.15 yr⁻¹).

Model element		Number of parameters
Trawl selectivity	Stationary	8
	Time-varying	8
Setnet selectivity		9
Hook-and-line selectivity		9
Recreational selectivity	Stationary	5
	Time-varying	21
Triennial survey selectivity		3
Recruit survey selectivity		1
CalCOFI survey selectivity		0
Recreational fishery effort		1
Growth		5
Recruitments		28
Total		98

available from the mid-1950s (Fig. 5), preliminary analyses indicated they had little or no effect on the model's final estimate of current stock size.

In the prior assessment, Bence and Rogers (1992) showed that bocaccio selectivity patterns were inadequately described by the age-based Stock Synthesis model (see Methot 1990). Like them, we used the length-based implementation of the model, although the selectivity curve for the pelagic juvenile rockfish survey was modeled as full vulnerability at age-1 and no vulnerability at any other age. Similarly, in the previous assessment, a component of the trawl fishery selectivity function was allowed to vary with time. We initially explored a model with constant selectivity and compared this to models where the ascending inflection point of the selectivity curve was allowed to vary. When interannual variation in that parameter was fully expressed (i.e., a value was estimated for each year), a gain of 49 log-likelihood units was realized at the cost of eleven new parameters, representing a significant improvement in fit. We were able to further simplify the model and reduce the total number of parameters by pooling five of these, without substantially affecting the total log-likelihood of the model. A similar procedure was used for the selectivity curve in the recreational fishery, except that two parameters were allowed to vary with time (i.e., the ascending inflection point and the initial selectivity).

Thus, the final "baseline" version of the bocaccio model included eleven log$_e$-likelihood components (i.e., $m = 11$) that together controlled the fit of the model to the data. These were components for: (1) the trawl fishery length composition data, (2) trawl fishery surface age composition
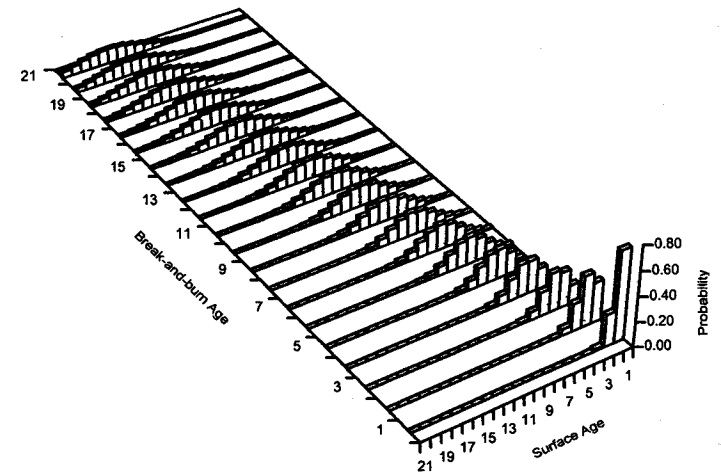
Figure 6.   Probability transition matrix used to generate predicted surface age distributions.

data, (3) trawl fishery break-and-burn age composition data, (4) hook-and-line fishery length-frequency data, (5) setnet fishery length-frequency data, (6) recreational fishery length-frequency data, (7) a recreational fishing effort series, (8) the triennial trawl survey time series of catch rate, (9) triennial survey length compositions, (10) the pelagic juvenile rockfish survey, and (11) the CalCOFI larval abundance survey (assumed ∝ spawning biomass). To fit the baseline bocaccio model a total of 98 parameters were estimated (Table 2). Also note that, once converged, the model solves for the fishing mortality rate that is required to produce an exact match to the observed landings, subject to the specific constraints imposed by the estimated parameter set.

Model Results

All of the age data used in the previous assessment (Bence and Rogers 1992) were based on surface ages. In our assessment we attempted to incorporate new age data that were derived from the break-and-burn method. This had the unfortunate effect of adding a new level of complexity in interpreting the age data. First, it became evident that, given the spread at older ages in the transition matrix, very little information could be extracted from surface ages (Fig. 6). Second, the percent agreement between reexamined break-and-burn samples was rather poor (Fig. 2). Finally, specific age determination criteria for bocaccio had not been rigorously vali-

dated and the two age readers indicated that, at least relative to other species of rockfish, bocaccio otoliths were difficult to decipher. The lack of validation implied that the break-and-burn ages could be biased. These issues led us to question the fundamental reliability of the different data sources, particularly the age composition data.

Concerns over the age composition data component were verified when the model was fit with (1) all the age data fully emphasized, (2) reliance on break-and-burn ages only, and (3) nil emphasis on any of the age composition data (Fig. 7). In the last case the model indicated a strong recruitment event of age-1 fish occurred in 1978 and that minor but above average events occurred in 1985 and 1989. These patterns were also evident in the trawl length composition data (Fig. 8), the recreational length composition data, and in the recruit survey (Fig. 4). The strong 1977 year class was, moreover, well known to California Department of Fish and Game biologists based on a tremendous influx of small fish in the 1977 and 1978 nearshore recreational fishery. In contrast, in the first two cases, wherein the age data were allowed to influence the fit of the model, the estimated time series of recruitments was blended in the 1980s and no dominant 1977 year class was evident.

Based on these findings, we classified the data into three general groups: primary, secondary, and tertiary (Table 1). This was done to improve the robustness of model outputs and to avoid model sensitivity to data that were noisy or were otherwise questionable. The primary data types were used in the estimation of growth, year-class strength, and population trend. The secondary data were used only to estimate selectivity patterns for the different gear types and the tertiary data were effectively omitted from the analysis except to highlight their deficiencies. To fit the model to the different data classes, we followed a simple, iterative scheme, i.e., (1) fitting the model with only the primary data types emphasized, (2) fixing parameters estimated in the first step and estimating selectivity parameters for secondary data types, and (3) repeating steps one and two until the model showed no further tendency to change. The resulting baseline model was characterized by trajectories of bocaccio summary biomass and spawning output that showed severe declines over the course of the modeled period, with terminal year values in the range of 5-10% of their maxima, which occurred in 1969 (Fig. 9). The obvious "bump" in these downward trends represents the strong 1977 year-class passing through the population.

Discussion

The assessment of bocaccio was complicated by a number of factors. In particular, we modeled the effects of four distinct fisheries on the abundance of male and female bocaccio. In addition, the trawl and recreational fisheries were marked by significant time-varying effects on selectivity.
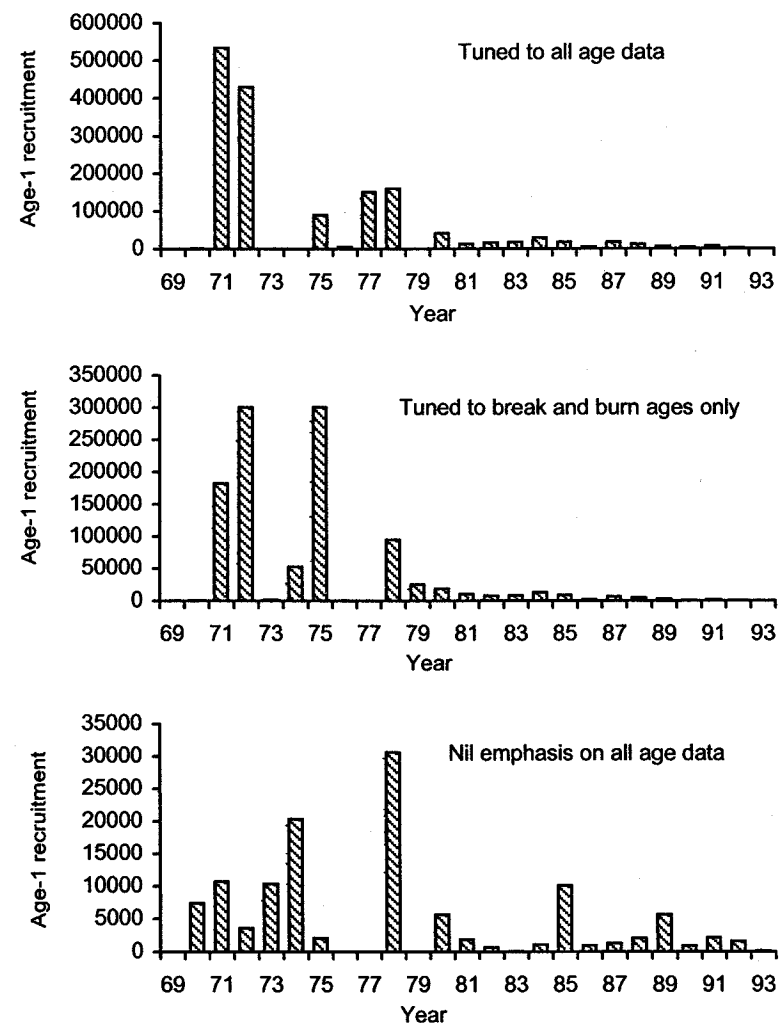

Figure 7.   *Time series of age-1 recruitments estimated with different emphasis levels on the age composition data.*
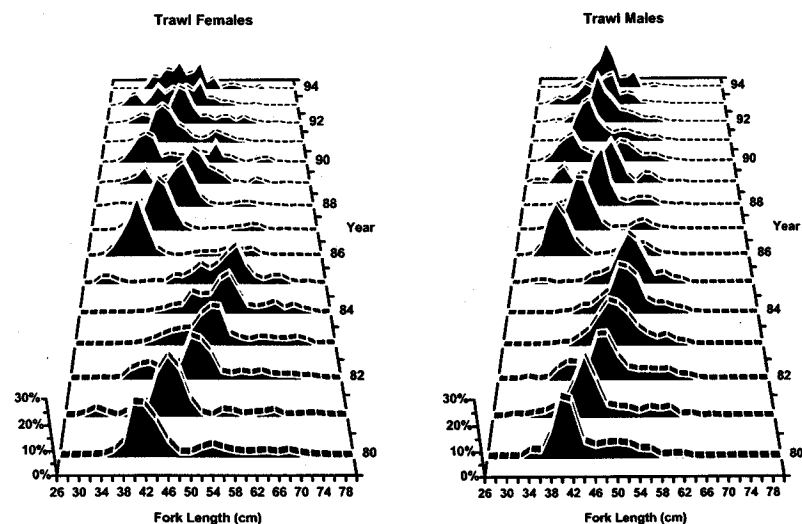
Trawl Females

Year

Fork Length (cm)

Trawl Males

Year

Fork Length (cm)

Figure 8.   *Relative length composition distributions of bocaccio caught in the trawl fishery (1980-1994).*
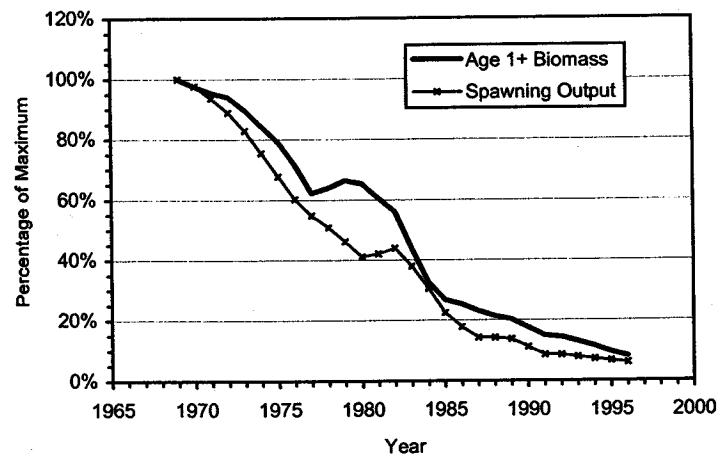

Figure 9.   *Estimated trends in summary biomass and spawning potential from the baseline bocaccio Stock Synthesis model.*
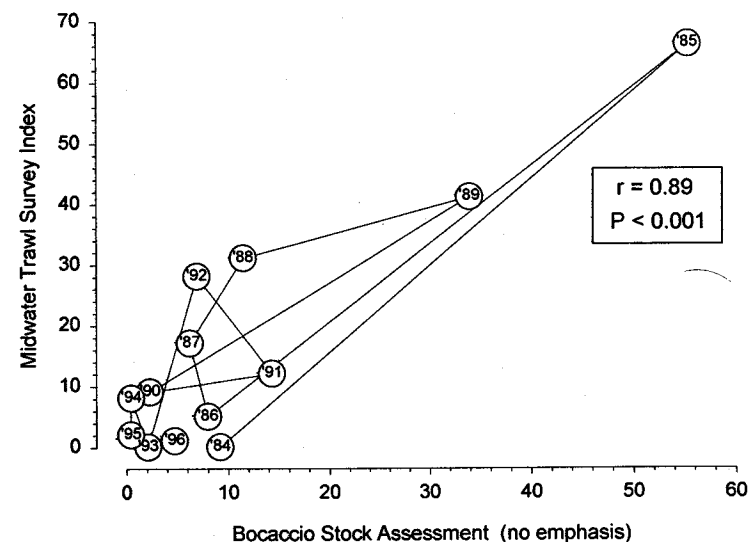
Figure 10.   *Relationship between the Southwest Fisheries Science Center's pelagic juvenile rockfish midwater trawl survey index of bocaccio abundance and year-class strength estimated from the Stock Synthesis model with no emphasis on those survey data.*

We also included three separate sources of fishery-independent information in the model. Perhaps most complex, however, was the inclusion of surface and break-and-burn age information in the assessment and unraveling the conflicting signals of those data with other information in the model.

In the case of bocaccio, the age data were of questionable utility, apparently due to problems with bias and imprecision (Figs. 2 and 6). In contrast, the length composition data were very informative and carried clear, unambiguous signals of strong year-classes passing through the fisheries (e.g., Fig. 8). Biologically, we believe that these two observations are related. The clear progression of modes in the length data was due to the rapid absolute growth of young bocaccio and the relatively brief seasonal expression of spawning. However, these two features exacerbated the interpretation of bocaccio otoliths. Rapid growth of subadult fish resulted in the proliferation of false annuli and accessory check marks in the otoliths, which were difficult to interpret, resolve, and validate through the application of marginal increment analysis.

We also utilized two new sources of information in a groundfish stock assessment, i.e., the SWFSC midwater trawl survey of pelagic juvenile rockfish abundance and the CalCOFI database of larval bocaccio abundance.

These complemented the traditional triennial groundfish trawl survey, which has been used extensively in previous stock assessments. To substantiate and validate the midwater trawl survey index as a relative index of recruitment, we also fitted our final model with zero weight on the recruit survey (Fig. 10). In this independent comparison the survey index was in full agreement with the model's interpretation of year-class strength, which was largely based on the available length-frequency data, particularly those from the trawl and recreational fisheries. It is our belief that in future applications this index will provide a reliable basis for projecting trends in biomass into the near future. Likewise, the CalCOFI database was used for the first time to index the relative spawning biomass of a groundfish. Except for the obvious outlier in 1970, it tended to closely follow the overall pattern of decline in spawning output observed in the base run model (Figs. 5 and 9). Based on our experience with these information sources, we encourage and advocate the use of both these fishery-independent auxiliary data sets in future groundfish stock assessments. However, one should always closely examine models for assumptions made about data quality.

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